Saskatchewan
Ministry of
Environment

ISO 14001
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Saskatchewan Forest Vegetation Inventory

Quality Assurance

Protocols for Inventory Assessment

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1.0 Program Overview

A joint task force made up of forest industry and Saskatchewan Environment, Forest Service representatives agreed on a standard for vegetation inventory in Saskatchewan, namely the Saskatchewan Forest Vegetation Inventory – Forest Planning Manual (Approved Version 4.0, July 2004).

The Saskatchewan Forest Vegetation Inventory (SFVI) is the primary information used for completing strategic level planning within the province. Forest industries that operate under Forest Management Area Agreements (FMA) and Term Supply Licence (TSL) holders with terms greater than 5 years, are required to complete detailed forest management plans in the licence area. Part of this agreement requires the completion and maintenance of a current SFVI for planning, operating, and reporting purposes.

The Forest Service has developed an audit process to ensure that consistent and reliable vegetation information is obtained on a province-wide basis. The objective is to ensure that the SFVI information meets the standards as required by the Saskatchewan Forest Vegetation Inventory – Forest Planning Manual (Approved Version 4.0, July 2004), without dictating the processes to follow to meet that end.

The audit process will validate the accuracy and quality of the inventory information by reviewing both the interpretation and digital data integrity.

1.1 Inventory Map Sheet Audit Process

The audits will be arranged and coordinated by the Forest Service. Beginning with the first map sheet to be audited, mapping activities are audited by Forest Service staff until the data collected are verified as complete and accurate. (See flowchart in Appendix C)

Auditing a sample of forest vegetation inventory maps can be done either after an inventory has been completed or concurrently as an inventory is in progress. The latter is preferred as this affords the opportunity for Forest Service staff to provide feedback to the contractor completing the work while the work is underway, allowing the contractor to correct identified errors while work is underway rather than having to redo work for large numbers of map sheets previously completed.

If the inventory has been completed, 10% of the base maps will be randomly selected and 30 - 50 polygons per map sheet will be randomly selected and quality assurance audited.

If the inventory is in progress for a block of maps, the contractor can submit selected map sheets to be evaluated by the Forest Service. After the selected maps pass the audit, work on the balance of the inventory continues with approximately 10% of the project area map sheets being audited in step with map production.

The Forest Service will prepare a report outlining the audit results for each completed SFVI project. If the inventory meets the required standards, a letter is written to the FMA holder confirming that the inventory was done to acceptable standards.

If the inventory does not meet acceptable standards, the noted discrepancies are to be rectified on the audited map sheets and that the non-audited map sheets are reviewed and corrected based on identified trends.

1.2 Aerial Photograph Audit Process

The purpose of the aerial photograph audit is to evaluate the suitability of the acquired aerial photographs for SFVI interpretation. This audit phase is the responsibility of the purchaser of the imagery.

Photographs should be acquired as close to the inventory date as possible. This will allow for the most recent anthropogenic and natural vegetation disturbances to be captured.

The photography should not be more than three years old by the time photo interpretation begins. Photographs must be taken in full leaf out conditions (June to September).

Flight and image densitometry reports (supplied by the aerial photography Contractor) for each film roll are examined to verify that the quality of the photographs meet the aerial photography contract specifications. These records are to be maintained by the imagery purchaser.

The standards for the acquisition, flight conditions, calibration, exposure, and processing are detailed in the current Interdepartmental Committee on Air Surveys (ICAS): Specification for Aerial Survey Photography 1998 located in Appendix II of the Saskatchewan Forest Vegetation Inventory – Forest Planning Manual (Approved Version 4.0, July 2004). The ICAS specifications may be updated periodically.

2.0 Saskatchewan Forest Vegetation Inventory Quality Assurance

2.1 Objectives

The objectives of conducting quality assurance on the SFVI are as follows:

1. To evaluate the quality of the product by sampling between 30 to 50 polygons\map sheet for 10% of the project area map sheets,
2. To improve the quality of all aspects of photo interpretation through evaluation and feedback,
3. To ensure that all field work and field data are collected to the established provincial standards,
4. To detect interpretive trends of individual interpreters,
5. To ensure the maintenance of specified SFVI photo interpretation standards, and;
6. To ensure the desired level of consistency is maintained between interpreters and therefore between inventory projects.

2.2 SFVI Audit Components

There are six main components or audit phases to the SFVI audit process.

1. Aerial Photo Preparation and Data Source Transfer*
2. Polygon Delineation
3. Digital Line Capture**
4. Field Calibration
5. Aerial Photo Interpretation
6. Digital Map Production

They are audited individually or in combination as follows:
* If softcopy methods are employed then these steps are not included.
** If softcopy methods are employed then this step is included with polygon delineation

2.2.1 Aerial Photo Preparation and Data Source Transfer

Auditing the preparation of hardcopy aerial photos for subsequent delineation and attribute interpretation includes transferring historical, air and\or ground based calibration data from the source medium (i.e. previous inventory photos, field plot cards) to the inventory photos from which the new inventory will be produced.

The audit of photo preparation is to ensure that the effective stereo area has been utilized to the best degree possible based on the forward and side overlap provided by the aerial photographs. The data source transfer is audited to ensure that historic data sources (those that are maintained in the inventory) and new data sources are transferred to within the tolerances specified, specifically that they are placed correctly within the polygons where they were installed in the field.

2.2.2 Polygon Delineation

Auditing the delineation of the project area (the stratification of uniform polygons based on significantly observable differences in vegetated or non-vegetated cover types) using hardcopy or scanned aerial photographs (softcopy), is to ensure that the polygon adjacency and minimum size standards of the SFVI (as a minimum) are met. Polygon delineation and minimum polygon size guidelines are detailed in Section 3.0 of the Saskatchewan Forest Vegetation Inventory – Forest Planning Manual (Approved Version 4.0, July 2004).

As stated previously, the audit for aerial photo preparation and data source transfer is performed concurrently with the audit for polygon delineation (if applicable).

2.2.3 Digital Line Capture

This audit step ensures correct capture of the line work to the digital environment, either through the process of orthophoto transfer and subsequent digital capture, or through direct digital capture in combination with delineation in a softcopy environment.

This audit is performed either after the completion of the delineation audit (hardcopy aerial photographs and orthophoto transfer), or at the same time as the delineation audit in the case of delineation/digital line capture completed using softcopy.

2.2.4 Field Calibration

The audit of field data collection determines if the accuracy of the field data components meet the SFVI standards (Table 1). The audit will focus on the quality of data collected for use as calibration data rather than the mensurational (procedural) aspects of the data collection. The intention is that the field audit be conducted at the same time as the project field crew(s) are in the field (preferably near the beginning of the field program) in order to minimize costs and ensure that feedback to the contractor is prompt.

This quality assurance step may not be required for all contracts. If required, the contractor will establish with the Forest Service, an orientation session to discuss field protocols and procedures for the aerial reconnaissance and ground plot programs, program logistics, and organization that will be employed for the duration of the field program.

Table 1 illustrates which base level inventory attributes will be audited and their required accuracy/precision, and point scores. All individual attribute scores are equal to 1 because each attribute is audited separately and not relative to the other attributes for each polygon. A minimum of 90% accuracy for each attribute, for each map, is required for quality assurance sign-off. A statistical explanation of this standard is listed in Appendix B.

Table 1. SFVI field attributes to be audited and required precision, scoring weight.

Attribute	Accuracy / Precision
Structure Type	Correctly assigned
Crown Closure – upper tree layer	+/- 10%
Leading Species Height - upper tree layer	+/- 1.5m (≥ 10m) or +/- 0.5m (<10m)
Species Composition - upper tree layer	± 10% by crown closure
Stand Origin – upper tree layer	+/- 5% Expressed to the nearest year
Crown Closure – lower tree layer (if applicable)	+/- 10%
Leading Species Height – lower tree layer (if applicable)	+/- 1.5m (≥ 7m) or +/- 0.5m (<7m)

Species Composition – lower tree layer (if applicable)	± 10% by crown closure
Stand Origin – lower tree layer (if applicable)	+/- 5% Expressed to the nearest year
Shrub Layer (if applicable)	Correctly described
Herbaceous Layer (if applicable)	Correctly described
Non-vegetated Surface Layer (if applicable)	Correctly described
Topographic Class	+/- 1 class
Soil Moisture Regime	+/- 1 class
Disturbance Features and Extent (if applicable)	Correctly assigned

2.2.5 Aerial Photo Interpretation

This audit is intended to determine if the aerial photo interpretation meets the minimum SFVI standards as detailed in the Saskatchewan Forest Vegetation Inventory – Forest Planning Manual (Approved Version 4.0, July 2004). The SFVI interpretation audit form is located in Appendix A.

2.2.6 Digital Map Production

This audit is the final check of the digital map products produced for the inventory project and involves the validation of the digital aspatial and spatial deliverables. This is also the final audit conducted for an inventory project.

3.0 Quality Assurance Protocols

The objectives of the Forest Service, by providing these guidelines for quality assurance auditing, is to ensure that contractors produce high quality and consistent inventory data. It is not the Forest Service's intention to dictate how the SFVI is to be completed, but to ensure that the SVFI is completed to consistent standards. The following subsections address, in greater detail, the audits for each of the major components of the inventory process.

3.1 Aerial Photo Acquisition

To ensure quality prints for all phases of the inventory, a test set of photo prints is to be requested from the aerial photo contractor. This is to ensure that ICAS 2004 specifications (or the most recent available) are met and the best contrast is identified before bulk printing.

The flight index map is checked to determine if the exact coverage for a given area was achieved. Compare the flight index map annotation to the corresponding photograph

annotation and ensure all photographs indicated on the flight index map have been received.

Every flight line is checked for:

1. Correct photo annotation,
2. Adequate forward overlap (±60%),
3. Total line coverage,
4. Adequate side overlap (±30%),
5. Gaps in coverage (missed areas or insufficient stereo coverage),
6. Sun spot, hot spots, or flares, and;
7. Damaged emulsion

If a gap in photo coverage is found, the aerial contractor is notified so that complete coverage can be guaranteed at the earliest opportunity.

3.2 Aerial Photo Preparation and Data Source Transfer

There are several methods used to prepare aerial photographs for delineation and data source transfer. The purpose of this audit is to ensure that the method selected is approved by the Forest Service and completed to the standards and tolerances specified by the contract. Most importantly, the photo preparation should ensure that the best effective stereo area is used to define the area on each photo that will be delineated and interpreted.

Data sources or ancillary data can be used to aid in SFVI interpretation process. Typical data sources include air calls, ground plots, temporary sample plots (TSP), permanent sample plots (PSP), and fire history maps. The transfer or initial digital capture of this spatial information must be conducted with sufficient precision and accuracy to ensure that both the historic plot locations are transferred accurately in stereo and the plot information (if accompanying the plot location) is transferred correctly.

3.3 Polygon Delineation

The purpose of delineation is to stratify the landscape into homogenous cover types (polygons) based on SFVI criteria. However, polygon delineation may be conducted to varying levels of detail depending on the inventory objectives of the licence holder or the Forest Service.

The audit will be conducted with respect to the contract specifications and in consultation with the contractor that completed the work. To ensure consistency, a 10% sample of the delineation from each photo interpreter conducting the delineation will be audited.

What remains constant is the need for the delineation to be completed consistently and neatly. Minimum polygon size and adjacency guidelines are outlined in Section 3.0 of The Saskatchewan Forest Vegetation Inventory – Forest Planning Manual (Approved Version 4.0, July 2004). Other guidelines are as follows:

1. Check the photographs for the accurate location of map sheet boundaries and stereo model lines. Map boundaries should be consist with the NAD 83 CSRS98 UTM map grid,
2. Check that polygons tie from photograph to photograph within a map sheet,
3. Check that all polygons tie to adjacent map sheets, and;
4. Check all the polygon type lines in the map sheet, looking specifically for; separation of moisture regimes and species based on SFVI specifications.

Hardcopy aerial photo preparation, data source transfer and pre-delineation are usually audited concurrently for quality assurance.

3.4 Transfer of Data to the Orthophoto Base Map

An orthophoto base map provides the 'base' onto which other information layers can be attached. Created from high elevation photographs (1:60,000 or 1:50,000), base maps normally contain hydrology, planimetric detail such as roads, trails, power lines, place names, etc.

Often, at the same time that photo delineation occurs, pre-existing base map data is verified for currency against the information provided by the new operational scale (i.e. 1:15,000) photos.

In the hardcopy environment, vegetation cover type lines derived from polygon delineated on the aerial photographs are stereoscopically transferred onto orthophotos. These polygon lines are digitized (or scanned from clear acetate overlays) and the resultant digital polygons are numbered. The objectives of this audit are to ensure that the standards of line transfer and capture are met.

In softcopy, a digital photogrammetric system that was first re-configured for photo interpretation for inventory applications in 1997. The delineation and digital line capture phases are completed concurrently. Therefore, quality assurance audits completed for delineation and transfer/digital capture are completed concurrently as well.

The purpose of this part of the audit process is to establish the accuracy with which the polygon lines were transferred from the interpreted photographs to the orthophoto (hardcopy) and subsequently captured digitally in a geographic information system (GIS).

3.4.1Tolerances for Orthophoto Transfer

The transfer of polygon boundaries to the Orthophoto (hardcopy process) will conform to the following standards:

1. All polygon boundaries must have a displacement no greater than 1mm at 1:15,000 when measured perpendicular to the source polygon boundary located on the interpreted aerial photographs.
2. If a line displacement greater than 1mm does exist, it must not exceed one-third the length of the polygon line when measured between two adjacent line connections. For example, if a polygon has a line displacement of 1.5 mm but the extent is less than one third the length of the polygon line, there is no error scored.

3. Polygon boundaries should not be less than 15 meters in width (≤1 mm @ 1:15,000).
4. Polygon boundaries are also checked for tie-in among adjacent polygons within the same map sheet and between adjacent map sheets. A polygon will be scored against if the tie-in lines with adjacent map sheets are off by more than 1mm.
5. Field plot center point, aerial photo center's, and aerial photo annotation (line, roll, exposure number, and date) must be stereoscopically transferred from the aerial photographs to the orthophoto and be correctly located (≤1mm at 1:15,000) on the base map at all times.
6. Polygon numbering is unacceptable if a given polygon:
    a. Contains label errors (multiple labels or missing label) for the ArcInfo coverage;
    b. Contains a polygon number that is not unique;
    c. Is a multipart feature (more than one polygon shares one attribute record) for ArcView shape file or ArcGIS geodatabase;
    d. Does not have a polygon number;
    e. Was not numbered sequentially (manual or auto numbered); or
    f. Has an illegible polygon number.

As no line transfer exists in softcopy, the 'orthophoto transfer' and associated audit checks are not conducted if this technology is used.

3.5 Field Calibration

The collection of accurately measured or estimated field data (i.e. Data sources) is critical to the accuracy of the SVFI, as this is the information that is used to calibrate the photo interpretation. If a field program quality assurance audit is recommended or required by a contract, the focus will be on the accuracy of the information collected (results) more than on the methodology and procedures employed to collect that minimum level of information (process).

Every effort will be made to conduct such quality assurance auditing as required while the field program is being completed. Where possible (preferable) the field audit will be conducted at the start of the field program to ensure that any feedback can be provided to the contractor before too much of the fieldwork is completed.

3.6 Attribute Interpretation

The attribute interpretation quality assurance audit will review the final delineation (final line adjustments arising from the more intensive polygon by polygon scrutiny of polygon integrity conducted during attribute interpretation) and the SFVI attribute interpretation.

A randomly selected number of polygons (5%) on each map sheet selected will be reviewed according to the SFVI attribute interpretation audit criteria presented in Table 2. The form used to conduct the SFVI photo interpretation quality assurance audit can be found in Appendix A.

Both the Forested and Non-forested polygons will be audited together. To pass an attribute interpretation quality assurance audit each audited map sheet must achieve ≥90% for every forested or non-forested attribute audited on a map sheet.

The equation used to calculate the percent agreement between the original interpretation and the quality assurance audit by attribute is defined as:

Acceptance is ≥ 90% for forested and non-forested attributes

1. $$\text{Agreement \%} = \left[1 - \left\{ \frac{\Sigma di}{\text{Total \# } \textbf{\textit{available polygons}} \text{ of the ith attribute audited}} \right\}\right] \times 100 = _____\%$$

* Where Σdi is the total weighted discrepancies of the ith attribute
* Available polygons refers to the # of polygons that the audited attribute appears in
* A 95% acceptance score must be used for tree volume related attributes.

Table 2. SFVI Attribute Interpretation Audit Criteria

Attribute	Accuracy / Precision
Photo Polygon Number	Correctly assigned and legible
Digital Polygon Integrity	Correct
Polygon Final Delineation	Correct
Land-use /Transportation Features	Correct
Aquatic Features	Correct
Structure Type	Correctly assigned
Crown Closure – upper tree layer	± 10%
Leading Species Height - upper tree layer	± 2m
Species Composition - upper tree layer	± 10% by crown closure

Attribute	Accuracy / Precision
Canopy Pattern - upper tree layer	± 1 Class
Stand Origin - upper tree layer	± 10 years
Crown Closure – lower tree layer (if applicable)	± 10%
Leading Species Height – lower tree layer (if applicable)	± 3m
Species Composition – lower tree layer (if applicable)	± 10% by crown closure
Canopy Pattern - lower tree layer	± 1 Class
Stand Origin – lower tree layer (if applicable)	± 10 years
Shrub Layer % and Species (if applicable)	± 20% by crown closure
Herbaceous Layer % and Species (if applicable)	Correctly described
Non-vegetated Surface Layer (if applicable)	Correctly described
Topographic Class	+/- 1 class
Soil Moisture Regime (SMR)	± 1 SMR class
Disturbance Features and Extent (if applicable)	Correctly assigned feature, extent ± one class
Disturbance Years (if applicable and known)	Correct

3.7 Attribute Transfer

The transcribing of attributes from photographs to coding sheets is audited to ensure that the attributes, as photo interpreted, are transcribed correctly to the coding sheets or to the database. This quality assurance audit is only conducted where attributes are not directly entered into a database during photo interpretation. Polygons selected for this quality assurance audit are the same as those selected for attribute interpretation quality assurance described in Section 3.4.

An individual attribute weight factor of 1 is applied to every polygon checked. An error is tallied (point loss) when any of the audited features are found to exceed tolerance limits. Attribute transfer audit scoring is recorded on the same form (spatial audit portion) used for quality assurance auditing attribute interpretation and base map transfer:

1. The minimum accuracy for this work is 90%, and;
2. Map sheets scoring less than 90% will have 100% of the coded attributes checked to determine the full extent of the discrepancy.

3.8 Base Map Transfer

Each selected polygon (the same polygons selected for the attribute interpretation, and attribute transfer audits) is examined for polygon transfer accuracy and tie-in precision with adjacent base features. The weight factor of 1 is applied to every polygon checked. An error is tallied (point loss) when any of the audited features are found to exceed tolerance limits.

Digital attribute database audit information is recorded on the same form (spatial audit portion) used for quality assurance auditing attribute interpretation and attribute transfer, and the criteria for calculating the percent accuracy tolerance per map sheet are based on the same formula as for the attribute transfer.

Appendix A: SFVI Quality Assurance Audit Form

SFVI PHOTO INTERPRETATION AUDIT

Company: **Date of Audit:** **Page of**

Attribute	Discrepancy weight	Map sheet number: _____ MAP POLYGON NUMBER																					Total Achieved	Total Possible	% score
Legibility	1																								
Attribute Transfer	1																								
Polygon Transfer	1																								
Adjacent Map Tie-in	1																								
Land Use	1																								
Aquatic Features	1																								
Stand Structure	1																								
Crown Closure %	1																								
Height	1																								
Specie Composition	1																								
Canopy Pattern	1																								
Stand Origin	1																								
Shrub (% cc and species)	1																								
Herbaceous (% cc and species)	1																								
Non-vegetated surface layer	1																								
Topographic Class	1																								
Soil Moisture Regime	1																								
Disturbance Features \ Extent	1																								
Disturbance Years	1																								

X – Discrepancy O – Noted not scored

Appendix B: Sampling Error and Audit Score

Audit procedures are subjective (based on production procedures and work experiences) while the audit process must be credible, repeatable and reliable. Thus, the method of sample selection must be random. Usually, a random or systematic sample size between 30 and 50 polygons per map sheet is the minimum reliable requirement.

If an attribute, by either field measurement or photo interpretation, has an error value exceeding the tolerance limits defined previously in Tables 1 or 2, the attribute will be scored against. This error refers to random errors caused by negligence, careless, or other human and system errors. The most difficult part of the audit is to determine the minimum random error percentages accepted by both parties. Three factors used in determining how much random error is acceptable are final product precision, audit sample size, and error percentage. This appendix will demonstrate how to calculate sampling error and give an appropriate passing score.

1. Sampling method

Sampling method determines sampling precision. An efficient and sound sampling method is essential to the success of the audit.

1). Sample unit is a polygon
This method is simple to apply, but error occurrence is not equal probability. As we known, a polygon contains of many attributes. When more than one attribute have errors, only one error will be penalized (highest score marked). The other errors are often noted. In addition, different polygons may have different number of attributes. The more attributes a polygon contains, the more errors the polygon probably gets.

2). Sample unit is an attribute of a polygon
This method is more complicate than the previous one. More sample set and calculation are required, but it is unbiased. When certain polygons have few attributes, post-stratify the sample into 2 strata. One stratum contains polygons with the attribute and the other one includes polygons without the attribute. Then, sampling error of the stratum with attribute is calculated only.

2. Audit score method

Audit score is a quantified (weighted) error of photo interpretation, line delineation, data transferring or GIS topology. Assigning fair scores to audited attributes is a key step to a successful audit. Although there are many ways to assign scores, they can be categorized into two types.

1). Audit by polygon.
Since sampling unit is polygon, audit by polygon will be the first choice. Thus, the following facts are often considered for assigning the audit score:

- Certain attributes are more important than others within a polygon;
- If errors exist in a sample polygon, only one error will be penalized (highest score marked). The other errors are often noted.

This weighted score method seems to be fair and convenient, but it is biased due to different polygons may contain different number of attributes. A polygon with more attributes will have a higher probability of error occurrence. In addition, if only the highest score is marked, the other attribute errors cannot be evaluated.

2). Audit by attributes
To avoid the above problems, audit should be carried out by attribute separately. Although this method needs calculating sampling error for each attribute, the weighted score procedure can be omitted. In addition, all errors will be marked and all attributes will be evaluated. Remediation/correction will be needed only for certain attributes with unacceptable percentage of errors.

Therefore, audit by attributes method is chosen for SFVI auditing.

3). Acceptance error percentage
Since attributes are audited separately, weighting scores for attributes are not necessary. Audit score, then, is truly a passing percentage or acceptance agreement %, which is equal to 1 – error%. The following sections will demonstrate what are the reasonable acceptance audit score or error percentages.

3. Confidence Interval of Audit Score

1).Binomial Distribution
Since an attribute audit has only two values, i.e. 1 (correct) or 0 (incorrect), the audit result is the binomial distribution:

$$Pr(a) = n!/[a!(n-a)!] * p^{n}(1-p)^{n-a}$$

Where
a = the number of successes in the sample
p = true probability of success
n = sample size

Two extreme cases of the binomial distribution can be represented by Normal approximation and Poisson approximation when population is infinite. When n is large and p & (1-p) both > 0.1, the Normal approximation can be used. When p or 1-p < 0.1 and population size is large, the Poisson approximation should be applied. In case of n*p > 50 and p < 0.1, the Poisson distribution can be calculated using the Normal approximation.

In audit process, since the allowable error is always very small, the binomial distribution should be calculated using the Poisson approximation or the following formula (Zar 1999):

Lower limit of Confidence Interval (CI)

$$L_1 = X / (X + (n-X+1)F_{\alpha(2),\nu1,\nu2})$$

where

X = error occurrence (number of incorrect interpretation)
= n-a

n = sample size (number of audited polygons per mapsheet)

$F_{\alpha(2),\nu1,\nu2}$ is Two tailed Critical Value of the F Distribution

v1 = 2(n-X+1) (numerator degree of freedom)

v2 = 2X (denominator degree of freedom)

Upper limit of CI

$$L_2 = (X+1)F_{\alpha(2),\nu'1,\nu'2} / ((n-X) + (X+1)F_{\alpha(2),\nu'1,\nu'2})$$

where

v'1 = v2+2

v'2 = v1-2

2).Hypergeometric Distribution

When sampling population is finite and sampling without replacement, audit result is a Hypergeometric distribution. To calculate the CI of the sampling error, we have (Zar, 1999):

Lower limit of CI for finite population

$$(L_1)c = (X-0.5)/n - ((X-0.5)/n - L_1)\sqrt{(1-(n/N))}$$

where

N = population size (number of polygons per mapsheet)

Upper limit of CI for finite population

$$(L_2)c = X'/n + (L_2 - (X'/n))\sqrt{(1-(n/N))}$$

where

X' = X+(X/n)

4. Examples of sampling error estimation

1). Assume there are 1000 polygons (N) on a map. The audit sample size (n) is 50 polygons or 5% of the total. If 48 of these polygons are found to be within the allowable tolerance error limit, it means that 48 polygons are acceptable and 2 polygons are not.

a). Infinite Population

When sampling with replacement,

n = 50 , p = 48/50 = 0.96, (1-p) = 0.04, X=2,

Then

$v_1 = 2*(50-2+1) = 98$, $v_2 = 2*2 = 4$

$F_{\alpha(2),98,4} \approx F_{\alpha(2),100,4} = 8.32$

$L_1 = 2/(2+(50-2+1)*8.32 = 0.0049$

$v_1' = 4+2 = 6$, $v_2' = 98-2 = 96$

$F_{\alpha(2),6,96} \approx F_{\alpha(2),6,100} = 2.54$

$L_2 = (2+1)*2.54/(50-2+(2+1)*2.54) = 0.1371$

Thus, when 2 errors occurred, CI is (0.0049,0.1371)

Or, (0.8629, 0.9951) for 96% of polygon passed audit.

b). Finite Population

When sampling without replacement,

$(L_1)_C = (2-0.5)/50-((2-0.5)/50 - 0.0049)* \sqrt{(1-50/1000)}$

$= 0.0055$

$(L_2)_C = (2+2/50)/50+(0.1370-(2+2/50)/50)* \sqrt{(1-50/1000)}$

$= 0.1347$

CI is (0.0055, 0.1347) for 2 errors

Or (0.8653,0.9945) for 96% of polygon passed.

The lower limit (0.8653) of the CI is much farther away from the mean (0.96) than the upper (0.9945) limit does. This means that although the expected audit passing mark is 96%, the worst case of the expected value might be 86.53% because of the sampling error. Note that finite population correction resulted in narrow range of CI and the narrowing effect will be determined by sampling intensity (n/N)

2). When changing the sample size error percentage, we have the following table:

Table B-4a. Confidence Interval by various Sample Size and Error %
For Recommended Acceptance Audit Score 95

Case	1	2	3	4	5	6
X	1	1	1	2	2	3
n	20	25	30	40	50	60
N	400	500	600	800	1000	1200
p	0.05	0.04	0.033333	0.05	0.04	0.05
1-p	0.95	0.96	0.966667	0.95	0.96	0.95
v1	40	50	60	78	98	116
v2	2	2	2	4	4	6
$F_{0.05}$	39.47298	39.47753	39.48117	8.336883	8.32074	4.906326
v1'	4	4	4	6	6	8
v2'	38	48	58	76	96	114
$F_{0.05}$	3.145303	3.066233	3.015657	2.579625	2.542933	2.3052
L1	0.001265	0.001012	0.000844	0.006114	0.004881	0.010432
L2	0.248733	0.203517	0.172169	0.169197	0.137138	0.139243
X'	1.05	1.04	1.033333	2.05	2.04	3.05
(L1)c	0.001866	0.001493	0.001244	0.006908	0.005517	0.011223
(L2)c	0.243764	0.199417	0.168682	0.16621	0.134698	0.137005

From the Table B-4a, it was clearly demonstrated that smaller sample size has a much larger sampling error even if its expected error percentage is the same (cases 1, 4 and 6). Since an error occurrence of 1 in 25 will result in the upper limit of expected mean error being approximately 20% (Case 2), the audit sample size should not be below 25.
For the minimum acceptance score 90, a sample size 20 may result in a sampling error over 30%. See Case 1 in Table B-4b.

Table B-4b. Confidence Interval by various Sample Size and Error %
For Minimum Acceptance Audit Score 90

Case	1	2	3	4	5	6	7
X	2	2	3	4	5	6	4
n	20	25	30	40	50	60	45
N	400	500	600	800	1000	1200	900
p	0.1	0.08	0.1	0.1	0.1	0.1	0.088889
1-p	0.9	0.92	0.9	0.9	0.9	0.9	0.911111
v1	38	48	56	74	92	110	84
v2	4	4	6	8	10	12	8
$F_{0.05}$	8.419079	8.385882	4.96658	3.763205	3.157879	2.792945	3.752319
v1'	6	6	8	10	12	14	10
v2'	36	46	54	72	90	108	82
$F_{0.05}$	2.784546	2.697973	2.437275	2.231957	2.092456	1.989925	2.208893
L1	0.012349	0.00984	0.021117	0.027925	0.033275	0.037591	0.024753
L2	0.316982	0.260306	0.265288	0.236638	0.218136	0.205058	0.212212
X'	2.1	2.08	3.1	4.1	5.1	6.1	4.088889
(L1)	0.013935	0.01111	0.022693	0.029434	0.034711	0.03896	0.026095
(L2)	0.311615	0.255821	0.261187	0.233241	0.215195	0.20244	0.209139

5. Error propagation

Mean Errors (ME) of all by-products will be accumulated in the final product in the following manner:

$$ME^2 = \Sigma\, MEi^2$$

Where i = 1 to m

m = number of attribute audited

Assume stand volume will be estimated by attributes such as, stand height, crown closure and stand area. When all 3 attributes have the same CI (0.0055,0.1346) of sampling errors:

$ME_{volume\ of\ lower\ limit} = \sqrt{(0.13^2+0.13^2+0.13^2)} = \sqrt{(0.0169*3)} = \sqrt{0.0507} = 0.2252$

$ME_{volume\ of\ mean} = \sqrt{(0.04^2+0.04^2+0.04^2)} = \sqrt{(0.0016*3)} = \sqrt{0.0048} = 0.069$

Thus, when each by-product has an allowable error < 15%, the final product allowable error will be much higher than 15%. Usually, an audit score mark 95% will have a lower limit of 15% CI when sample size is about 50. After error propagation applied for 3 attributes, the lower limit of the mean error will increase to about 25%. Therefore, larger allowable errors of by-products may result in an unreliable final product.

6. Sampling Size

Sample size plays an important role in determining sampling error. The smaller a sample size, the larger the sampling error. Increasing the sample size will narrow the range of Confidence Interval, but will not affect mean value of the error occurrence because random error is determined by quality of the photo interpretation.

In a typical forest map, there are on average approximately 1000 polygons. Often, a sample size of approximately 50 polygons is selected. Attributes like aquatic features, transportation roads, and disturbances may only occur in a few polygons.

In other cases, maps may have large areas of farmland or lakes, and hence such maps may have a small number of forested polygons available to sample. In these cases a smaller sample size (>25) will have to be used.

7. Conclusion

Since the audit samples are randomly selected, sampling error should represent the set of maps or polygons. The audit criteria for each attribute have a defined tolerance range for photo interpretation. From the above demonstration, a 96% success of passing the audit may have a 13.47% sampling error when sample size is 50. To ensure the high quality of each attribute collected, an acceptance agreement of 95% must be realized for each attribute, see Table B-7a. However, when cost is limited, **a minimum acceptance agreement of 90% can be used for attributes that are not related to tree volume**, see Table B-7b.

Table B-7a. Recommended Acceptance Score and Sample Size

Sample Size	25	30	40	45	50	60
Sampling Intensity %	5	5	5	5	5	5
Error Occurrence	1	1	2	2	2	3
Acceptance Score %	96	96.7	95	95.6	96	95
Lower Limit of Sampling Error %	19.94	16.87	16.62	14.88	13.47	13.7

Table B-7b. Minimum Acceptance Score and Sample Size

Sample Size	25	30	40	45	50	60
Sampling Intensity %	5	5	5	5	5	5
Error Occurrence	2	3	4	4	5	6
Acceptance Score %	92	90	90	91.1	90	90
Lower Limit of Sampling Error %	25.58	26.12	23.32	20.91	21.52	20.24

Considering error propagation, sample size of tree volume related attributes, such as Height and Crown Closure, must be more than 45 when sampling intensity is 5%.

The recommended acceptance agreement of 95% appears to be high, but it is actually not. It is easy to demonstrate that acceptance agreement of 95% of audit by attribute is less strict than acceptance agreement of 80% of audit by polygons. Imaging that when 15 different errors occurred in 50 samples, the error percentage is 15/50=30%, which fails the old method of audit by polygon. However, when using the new method of audit by attribute, even 2 errors out 40 samples for each attribute will give us a 5% error percentage. A total 15 attributes have a total of 30 errors, but all attributes still pass the acceptance score 95.

Other benefits of the audit by attribute method are:

- Lower confidence interval is less than 20% at 95% probability for any attribute. In other words, the product accuracy is at worst 80% with 95% probability, but the expected accuracy is 95%.
- When an audit fails, only the specific failed attribute needs to be addressed. The result is clear and accurate.
- No arbitrary score weights assigned to different attributes. It simplifies the evaluation process. No subjective judgement calls are needed resulting in less arguments between the auditor and client.

8. Reference

Zar, J. H. 1999, Biostatistical Analysis, 4th Edition. Prentice Hall.

Appendix C: Forest Service SFVI Audit Process Flowchart